New Concept of Stiffness Improvement in Paper and Board

Yung B. Seo
Chungnam University

Abstract

A new concept of stock preparation for the increase of bending stiffness in paper and board was proposed. The 'stiff' fibers, which were mechanically not treated or treated slightly to remove fiber curls, were combined with extensively refined fibers (ERF) to produce higher stiffness papers than those where the whole fibers were refined. The combination of 'stiff' fibers and extensively refined fibers produced higher stiffness at the same tensile strength than the control furnish, in which all the fibers are refined together. In this concept, the fibers from recycled papers could be as much useful as the virgin fibers as long as they are stiff enough or they can produce highly bondable fiber fractions by extensive refining. Use of the concept in real paper mill needs considerations such as increase of refining energy, slower drainage, and added drying burden, but savings of wood fibers, utilization of more recycled fibers, and increase of physical properties may offset the negative concerns. The success of this concept implementation in mills, therefore, depends on the wood fiber market around the mills and the proper decision making for the papermakers about how to apply this concept.

Key word : Stiffness, Tensile strength, Fines, Composite material, Stress distribution, Stress singularity, Recycled fibers, Stiffness improvement

Introduction

Increasing stiffness in paper and board without reducing other physical properties has been a dream come true and one of the most favorite subjects to the paper-makers (1-4). This is because the stiffness in paperboard is the one of the most required properties to make price difference from the other competitors, and even in wood-free and coating grades, stiffness is a limiting factor for proper converting and printing processes. In printing and writing papers, smoothness is the most important required properties. To increase smoothness highly, increase of calendering pressure is essential while thickness reduction will follows. The reduction of paper thickness always causes stiffness reduction. It is normal practice to keep minimum smoothness while maximizing paper thickness to increase stiffness in white paper grade. Efforts to reduce basis weight while keeping physical properties usually fails mostly due to reduction of stiffness.

Making multiply is the best strategy to increase stiffness while keeping other physical properties. Besides, multiply can use low grade pulp in the middle-ply to reduce cost without hurting board properties. The stiffness in paperboard is the one of the properties to determine its quality, and in linerboard and medium, is a factor to decide their compressive strength.

Many studies (5-9) were done to increase stiffness. Impregnation of pectin or other chemicals to the board or use of starch are very common, but are expensive and difficult to pursue in the processes. A few studies showed success by making changes of fiber properties through heat treatment or use of crosslinking chemicals. Use of mechanical pulp instead of chemical pulps (7) or modification of wet pressing (5) affected the stiffness. However, there are no studies available to use extensively refined fibers (ERF, hereafter) along with 'stiff' fibers to increase paper stiffness.

The Concept of Stiffness Improvement

In this study, ERF was used as bonding agent and the 'stiff' fibers are used as structure elements to keep the paper thickness. The ERF was used as matrix materials and the 'stiff' fibers as filaments if we use composite material concept. By making the paper such a way, we could keep the breaking length at the same basis weight, but at higher thickness, which in turn, generates higher stiffness (stiffness is proportional to the third power of paper thickness). One fact to remember is that the refining energy and the drainage time for this high stiffness paper might be higher. Long nip press (LNP) and extended nip press (ENP) could be used effectively to reduce the drying burden in the proposed process, which utilize the most out of the mechanical potentials of fibrous materials.

Extensively Refined Fibers (ERF)

The extensively refined fibers (ERF) are not fines that were defined previously by several researchers (10~13). One of the definitions of the fines is that they pass through 200 mesh screen (10). A few researchers classified the fines as primary and secondary fines (11,13). The primary fines are the ones obtained before refining while the secondary fines are the ones generated only by the refining action. In waste paper, the 'primary' fines are the sum of the primary fines from previous furnish and the secondary fines from the previous refining (13). To define ERF, we used different hole size screen from that of TAPPI standard freeness tester to obtain a new 'freeness'. In Figure 1, we observe a point where the Canadian standard freeness (CSF) rises as very low freeness level as we continue refining. That deflection point was the point we chose to be ERF for LBKP. This behavior can be explained in this way. More fines will be generated by the continued action of refining, and the screen holes of the standard freeness tester becomes too large to hold the fines. Only fibrous materials larger than screen hole size can make the drainage rate slower in the CSF tester. At very high level of refining, we witnessed that the freeness of LBKP, which was once around 80 ml CSF became greater than 500 ml CSF by continued refining. When we changed the screen of the standard freeness tester to 100 mesh metal screen with 8% open area and we used 0.1g of furnish instead of 3g, we could make a continuously decreasing curve much longer than CSF result as in Fig. 1.

This study was intended to prove the effectiveness of the concept, which is to increase paper stiffness at the equal basis weight without lowering other mechanical properties such as breaking length. Two different series of experiments were made to confirm the composite material concepts.

Results and Discussions of Experiment No. 1

In the first experiment, NBKP and LBKP were mixed with the ratios of

80:20 to make the handsheets of three different basis weights (115g, 230g, and 345g/m2) in williams handsheet machine (non-oriented rectangular handsheet) and Dynamic sheet former (oriented rectangular handsheet). The NBKP was from unknown source and the LBKP was from northern hardwood mixture. The ERF was prepared by refining the LBKP for 60 minutes in Valley beater. The final freeness of the ERF was about 100 ml CSF and 500 ml in a new freeness tester. The control furnishes were prepared by mixing 20% NBKP and 80% LBKP, and was refined together in Valley beater for 12.8 minutes. Trial furnishes (Trial-A, Trial-B, and Trial-C) have three different fiber compositions as shown in Table 1. The freenesses of the refined hardwood and the refined softwood in Table 1 were 500 and 600 CSF, respectively. When changing the fiber compositions of the trial furnishes, we calculated the total refining time accordingly. We controlled the wet pressing to make the density of the trial sheets (Trials) as close to the control sheets (Controls) as possible. All the physical properties of the samples are shown in Tables 2 and 3. Graphical representation of the handsheet properties were also shown in Figure 2.

Every trial handsheet from Williams and Dynamic sheet former has higher stiffness than control handsheet at equivalent or better tensile. Trials of high basis weight papers had more improvement in tensile strength and internal bond, and less improvement in stiffness. Trials of low basis weight papers had the highest improvement of stiffness. It seems that the fines were retained more to the high basis weight handsheets and they increased fiber bonding to make tensile strength and internal bond high. More bonding of the Trials reduced the bulking effect of 'stiff' fibers in the composite material concept, and the stiffness improvement of the Trials was not great in high basis weight handsheets. All the Trials improved surface smoothness. The differences between Williams and Dynamic handsheet seems to be caused by the fiber orientation and the fine retention. Dynamic handsheet former uses more porous wire than Williams, that might cause less fine retention and lower bonding properties. If white water were used as in real paper mill, the bonding property could have been improved more. If the Trials had lower density than the Controls, their tensile strengths could have been close to the Controls, and their stiffness improvement could have been higher.

Results and Discussions of Experiment No. 2

In the second experiment, we used NBKP, which consisted of mostly Southern pine and a little fraction of Oak, and LBKP, which was a mixture of 80-90% of Oak and 5-15% of Gum, respectively. Handsheets were prepared from Williams sheet machine. The control sheet is a mixture of hardwood : softwood in 70:30, and they were refined together. The trial sheets were prepared with the mixture of unrefined hardwood: refined softwood: ERF in 50:30:20. The unrefined hardwood was actually tickle-refined to remove fiber curls by Valley beater beating without load. The ERF was prepared with double disk refiners in a paper mill by repetitive recirculating the hardwood furnish until desired quality was reached.

Table 4 and Figure 3 showed the effectiveness of the composite material concept, where stiffness improvements were very notable without losing tensile strength. The densities of the Trials were lower than the Controls, but tensile strength of the Trials were equivalent to or better than those of the Controls.

The stiffness improvement of Experiment No. 2 was much greater than that of Experiment No. 1. We believe it is quite possible. The stiffer the 'stiff' fibers are and the more the ERF is bondable, the higher the stiffness improvement of the composite concept paper will be without losing other bonding properties. It can be said in reverse way, too. If the 'stiff' fibers were not stiff enough, and the ERF were not excellent in bonding, the stiffness improvement of the composite concept paper could be insignificant.

The Trials need more refining energy to have the same density as Controls. More refining energy causes more drainage time. More refining energy and the drainage time are the trade-off of the mechanical property improvement in the Trials, which otherwise needs more fibers to achieve the same effects. To estimate the need of more fibers, following calculation could be made.

$$S = \frac{Et^3}{12} \qquad (1)$$

Where, E = Young's modulus of paper
t = paper thickness
S = paper stiffness

To increase the stiffness from S to S′ at the same Young's modulus (or same density), we need to increase the thickness of paper from t to t′ by increasing paper's basis weight.

$$\frac{t'}{t} = \left(\frac{S'}{S}\right)^{1/3} \qquad (2)$$

If we assume the increase of thickness is equivalent to the increase of basis weight by percentage, we can estimate the basis weight increase for the Controls to make their stiffness up to Trials. To increase stiffness by 20% by increasing paper thickness (or basis weight), we need 6.2% higher thickness or more fibers.

Discussions of the Composite Material Concept

Why does the use of ERF with 'stiff' fibers, the concept of which is analogous to the composit material concept (matrix for fines and filament for 'stiff' fibers), give higher tensile strength and stiffness than conventionally refined fibers at the same tensile strength? It seems that the distribution of stress will be more uniform for the 'composite material' paper, in which the void in the paper will be filled with short fibers and fines and thereby, stress singularities around the area of fiber-to-fiber bonding will be mitigated at the time of loading. Total area of fiber contact also seems to be increased by bridging between the fibers located quite a distance away. Thereby, the 'stiff' fibers can establish significant amount of fiber contacts without the need of fiber flexibility. The porosity of 'composite material' paper is usually much lower than conventionally refined one. This supports the idea that the voids in the 'composite material' paper is filled with short fibers and fines to make closed sheet. They may bridge fibers of some distance mechanically to add extra paper strength and may reduce the severity of stress singularities upon loading.

To implement this composite material concept in the mill, more refining energy, slower drainage, more drying burden are expected and they are the trade-off of the mechanical property improvement, which, otherwise, needs more fibers to achieve the same effects.

Conclusions

We showed the improvement of stiffness in our handsheet study without lowering other essential physical properties. The concept we used was to use structure element to make the paper bulky, which could be a 'stiff' fiber with minimum mechanical treatment, and to use bonding element to make the fiber bonding as strong as possible. Long fiber fraction such as softwood fibers could be mixed together to satisfy other essential properties such as folding endurance and tear strength. The quality of bonding elements could be a critical factor in some instances, and in our experiment, we used only the extensively refined fibers from virgin fibers as bonding elements. Within our experimental results, we made following conclusions.

* The combination of 'stiff' fibers and highly bondable fibers (ERF) produced higher stiffness at the same tensile strength than the conventional furnish, in which all the fibers are refined together.
* The stiffness improvement depends on the stiffness of the unrefined fibers, and quality of the extensively refined fibers (ERF). Therefore, to improve stiffness, selection of fibers and selection of fiber preparation processes are equally important.
* This concept may need more refining energy, slower drainage, and more drying burden.

The success of using the proposed concept to improve stiffness depends on the fiber market around the individual mill and the proper decision making by the papermaker about how to implement the concept. This is because the source of bonding elements could be any recycled fibers as long as they works properly, and 'stiff' fibers could be any hard-to-collapse fibers. One should also consider the mill machineries to allow more drainage and refining energy.

References

1. Kumar, V.B., Kumar, N., Studies on variations in properties of Indian paperboards, IPPTA 21, no. 3:54-62, Sept. 1984
2. De Ruvo, A., Optimal blends for stiffness and strength of board and liner, Svensk Papperstid. 82, no. 3:68-69, 81, Feb. 1979
3. Retulainen, E., Nieminen, K., Fiber properties as control variables in papermaking?; Strengthening interfiber bonds and reducing grammage, Pap. Puu 78, no. 5: 305-311, May, 1996
4. Butterworth, G.A.M., Practical and theoretical property requirements of fibrous and filamentary raw materials employed in the manufacture and reinforcement of nonwovens and paper, Proc. IUPAC/EUCEPA Symp. Man-made polymers Pmkg. : 159-74, Helsinki, June 1972
5. Back, E.L., Higher press-section dry-solids content with or without increased paper density, Svensk Papperstid. 90, no. 6:116-125, March, 1987
6. Meineke, A., Influence of the sheet formation method on the properties of multiply paper and board, Eucepa Conf. 18, Paper No. 11: 14 pages; May 21-24, 1979
7. Eriksen, J.T., Gaure, K., Hauan, S., Mechanical pulps in board for implement of bending stiffness, Norsk Skogind. 32, no. 5: 105-107, May, 1978
8. Tamdoo, P.A., Kerekes, R.J., The effect of beating and low amplitude flexing on pulp flexibility, J. Pulp and Paper Science 15, no. 1: J36-42, Jan. 1989
9. Muhlhauser, M., Stock preparation technology for folding boxboard from waste paper, Papier 46, no. 10A: V94-100, Oct. 1992
10. Htun, M, and De Ruvo, A., Svensk Papperstidining 81(16):507, 1978
11. Mancebo, R., and Krokoska, P., Papir a Celuloza 36(11): V75, 1985
12. Sandgren, B., and Wahren, D., Svensk Papperstidning 63(24):879, 1960

13. Waterhouse, J., and Omori, K., Products of Papermaking, edited by Baker C., Pira International, Vol.2:1261, 1993

Table 1. Furnish comparison for the handsheets (Experiment No. 1).

Samples	Unrefined Hardwood	refined Hardwood	refined Softwood	Fines	Total Refining Time
Control	0	80	20	0	12.8
Trial-A	60	0	20	20	14.0
Trial-B	40	20	20	20	16.2
Trial-C	0	60	20	20	20.6

Table 2. Physical properties of the handsheets from Williams type handsheet machine (Experiment No. 1).

Samples	Density (g/cc)	Tensile St.(lb/in)	Internal Bond	Taber Stiffiness (g*cm)	Sheffield Roughness(sec)
115g/m^2					
Control	0.65	33.37	135.4	6.29	331
Trial-A	0.66	33.09	130.0	8.27	319
Trial-B	0.67	34.05	127.9	8.00	312
Trial-C	0.66	36.39	152.4	8.59	318
230g/m^2					
Control	0.67	61.40	140.9	59.4	354
Trial-A	0.68	68.93	154.6	62.9	325
Trial-B	0.70	66.75	185.7	58.8	322
Trial-C	0.68	67.43	200.8	62.4	345
345g/m^2					
Control	0.65	91.60	130.0	211.3	372
Trial-A	0.64	98.30	181.4	227.1	345
Trial-B	0.68	96.00	204.9	209.8	352
Trial-C	0.67	103.00	234.0	215.5	383

Table 3. Physical properteis of the handsheets from Dynamic sheet former (Experiment No. 1).

Samples	Density (g/cc)	Tensile St.(lb/in)	Internal Bond	Taber Stiffiness(g*cm)	Sheffield Roughness(sec)
115g/m^2					
Control	0.60	28.34	135.1	6.87	3031
Trial-A	0.58	27.00	131.5	7.34	286
230g/m^2					
Control	0.68	65.24	177.2	55.15	323
Trial-A	0.64	58.37	166.2	62.94	325
Trial-B	0.67	67.21	164.4	60.96	298
Trial-C	0.68	75.89	204.5	61.24	293
345g/m^2					
Control	0.67	96.43	169.7	196.4	329
Trial-A	0.62	87.79	165.3	208.8	330
Trial-B	0.64	100.1	161.9	211.8	328
Trial-C	0.67	112.8	201.5	213.3	323

Table 4. Physical properteis of the handsheets from Williams handsheet machine (Experiment No. 2).

Furnish composition : (Unrefined hardwood : Refined softwood : ERF = 50:30:20)

Trial-A : ERF was prepared from Eucalyptus LBKP.

Trial-B : ERF was prepared from the hardwood shown in the furnish composition.

	Basis Wt. (g/m^2)	Density (g/cc)	Breaking length, Km	Stretch,%	Taber stiffness, (g*cm)	Porosity (sec./100cc)
Control-L	78	0.686	5.55	3.62	2.22	34.26
Control-M	122	0.730	5.71	4.43	6.82	67.48
Control-H	166	0.749	5.40	5.01	18.86	74.08
Trial-A-L	78	0.557	5.86	3.50	2.60	51.62
Trial-A-M	122	0.570	6.17	3.98	10.52	117.2
Trial-A-H	166	0.617	5.94	4.20	22.95	132.4
Trial-B-L	78	0.530	5.64	3.17	3.01	67.4
Trial-B-M	122	0.605	5.68	3.83	10.04	98.4
Trial-B-H	166	0.620	5.51	3.70	24.77	109.8

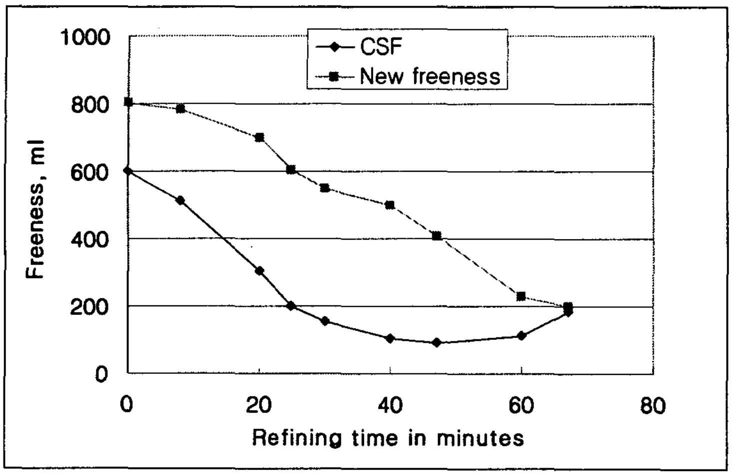

Figure 1. Canadian standard freeness vs. new freeness

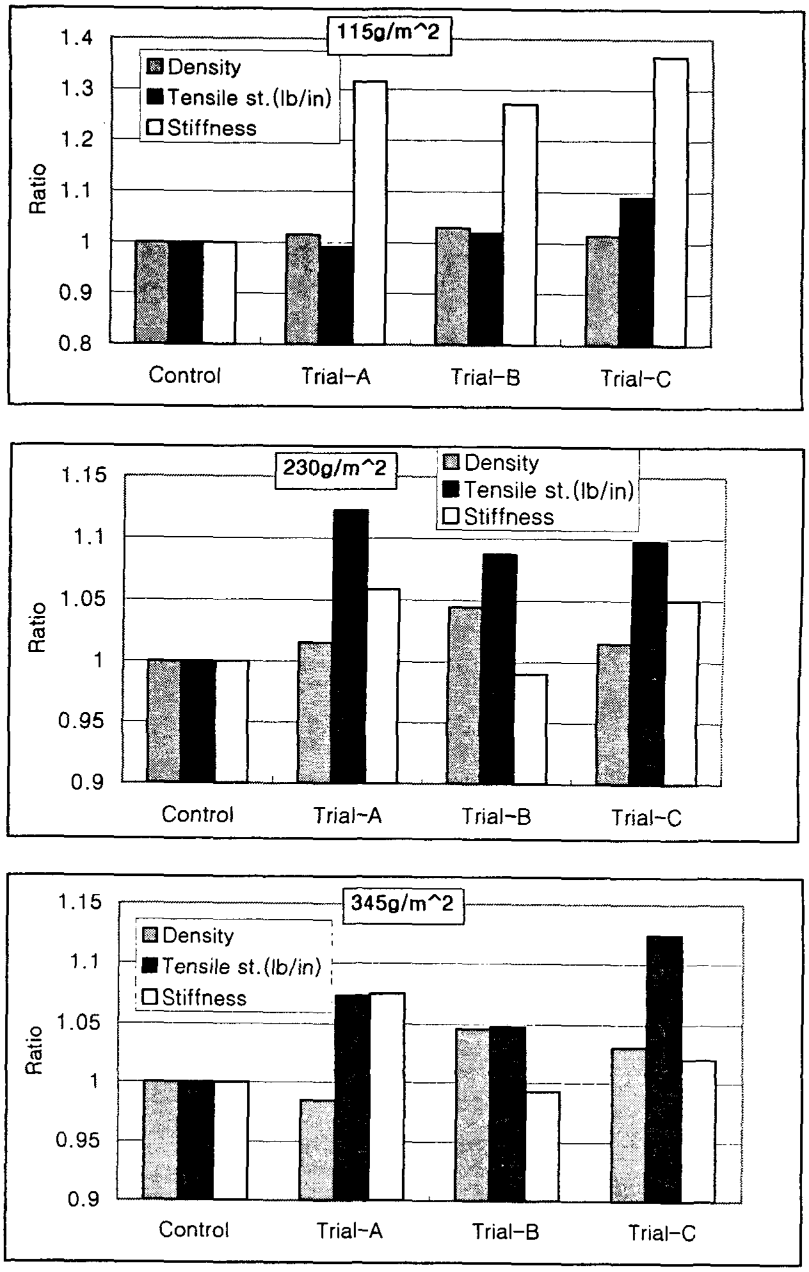

Figure 2. Comparison of tensile strength and stiffness of the handsheets from Williams handsheet machine.

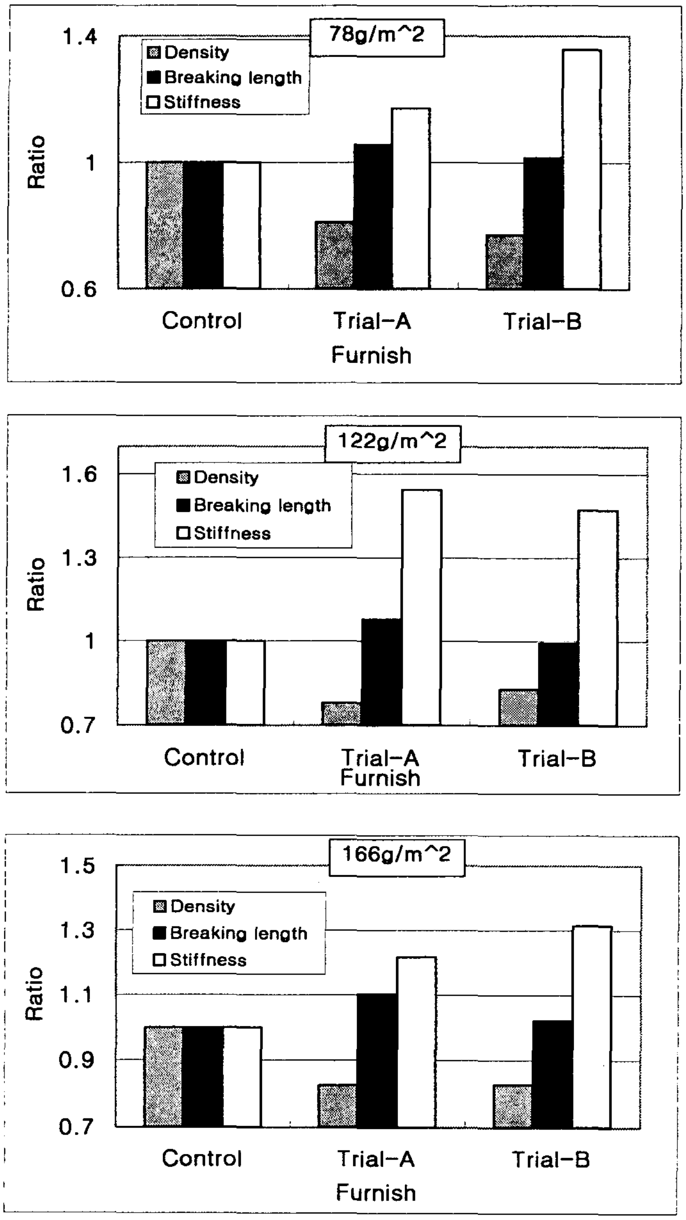

Figure 3. Comparison of density, breaking length, and stiffness of the handsheets.